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Spin-flip and domain wall magnetoresistance in quantum magnetic nanocontacts

N.Kh. Useinov *, L.R. Tagirov

Kazan State University, Kazan 420008, Russian Federation

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ABSTRACT

The theory of nanosize point contacts made of ferromagnetic metals is developed. A general quantum scattering theory is applied to calculate magnetoresistance of a nanocontact with a domain wall located in the constriction. The exact solution of the electron motion in a potential of the linear domain wall is used as a zero-order approximation. Spin-flip and spin-conserving quantized conductances of the nanocontact are calculated by the perturbation theory by the difference between the model and the Cabrera–Falicov potentials of the domain wall. It is explicitly shown that spin-flip conductance imposes natural limitation on magnetoresistance of the point contact, which otherwise diverges in the regime of complete spin-rectified conductance through the contact.

1. Introduction

Recent experiments on ballistic magnetoresistance (BMR) of nanosize point contacts between ferromagnetic metals have shown a giant enhancement of magnetoresistance in a weak magnetic field at room temperature [1–11]. The magnetic nanocontacts were proposed as a physical basis for a new generation of magnetoresistive sensors and read heads for computer hard disk drives [12]. The theory of magnetic nanocontacts considers the classical regime of conductance through the nanocontact [2,13], as well as the quantized conductance [14–19]. It was shown that magnetoresistance of a magnetic point contact is enhanced when conductance approaches the ballistic (collisionless) regime at the distances of the order of the contact size [2,13]. It can be of few hundred percent at experimentally approved polarizations of the conduction band in iron-group ferromagnetic metals. In the regime of quantized conductance, BMR of the quantum point contact experiences the huge enhancement at first few open conduction channels for the parallel (P) alignment of magnetizations in contacting single-domain ferromagnets [16–19]. Moreover, at a certain range of the contact size the P alignment conductance is open only for one spin projection of conduction electrons. Then, the current through the nanocontact is fully spin-polarized in spite of the spin-polarization of the conduction band being far below 100%. The nanocontact serves as an ideal spin-current rectifier. At the same time, the antiparallel (AP) alignment conductance is zero because of the conductance quantization [16–19]. This spin-blockade feature [18] of the quantum magnetic contacts results in the infinite BMR as long as the electron spin is conserved upon transmission through the point contact (see Fig. 1b and 2b of Ref. [16], Fig. 1b and 2b of Ref. [17], and Fig. 2d of Ref. [18]). It is clear, however, that any spin-reversal process creates bypass conductance which lifts off the blockade of the AP conductance by quantization. The spin-reversal process should immediately introduce a natural cut-off of magnetoresistance preventing its unphysical divergence.

Several spin-reversal mechanisms can be considered, however, the mistracking of the domain-wall (DW) profile by the conduction electron at the AP alignment of magnetizations seems to be a common and dominating process of the spin-flip [20,21]. For the smooth, unconstrained, 40–100 nm thick DW in the iron-group ferromagnetic metals, the DW magnetoresistance is exponentially small because the conduction electron adiabatically follows the slowly varying DW profile [22]. In nanosize magnetic contacts, DW can be as thin as the contact size [23–26]. Then, the mistracking becomes significant, and the quantitative consideration of the spin-reversal by the DW makes sense. Using the Cabrera–Falicov model [27] we explicitly demonstrate that the magnetoresistance is constrained against divergence by the electron spin-reversal upon the DW profile tracking.

* Corresponding author. Tel.: +7 834 2315200.
E-mail address: nuseinov@mail.ru (N.Kh. Useinov).

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